Searching Information from Screen Maps

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Abstract. Geographical information and digital maps are integrated in many ways into our every-day life through various GIS solutions. Screen maps and map interfaces should be easy-to-use for many kinds of user groups. Since digital maps have opened new ways to use geographic information, screen map users are facing new kinds of perceptual and cognitive challenges. There is, however, quite little knowledge of how people find information from a screen map. This paper describes a study where geographic objects were searched for from a screen map by using either zooming or scrolling. The aim of the study was to find out, whether there is a difference in search performance between different map user groups. Half of the participants were novice users; half of them were more experienced with screen maps. The searched-for object was shown on an index map, which was either visible during the whole trial or flashed shortly in the beginning of a trial. Participants' eye movements were recorded. Our results suggested that experience with GIS, screen maps and computers had an effect on search performance. Experienced map users searched for map objects faster than novices. They apparently interpreted map information and analysed it more efficiently than novices. Scrolling was a more efficient method to move around a map than zooming. The mode of presentation of the index map had only a small effect. An index map flashed shortly at the beginning of a trial seemed to be sufficient.

1 Introduction

Nowadays GIS solutions and applications are an essential part of our every-day life. Since there is many screen map applications and people use them from many types of computers, there is a need to study how people read digital maps (Burnett & Kalliola 2000, Cartwright et al. 2001, Slocum et al. 2001). However, although paper map reading has been studied quite much, reading from digital maps and map interfaces has been studied to a lesser degree.

Screen maps differ from static paper maps in many different ways. For example, screen maps make it possible to move along the map and change scale, utter sounds, view motion, or the colour and content of the map. Interacting with screen maps is a demanding task, as you have to interpret cartographic information at the same time you use the map interface. For example, you have to find right buttons for desired actions, interpret the map content in order to understand its message of the geographical dimensions and wait for screen refreshes. You can manipulate a map view either by zooming or scrolling. When you zoom you change the scale of the map and when you scroll you move along its surface. Screen maps make it also possible to move along a geographical space both vertically and horizontally.

2 Eye Movements and Visual Search for Map Objects on Screen Maps

Visual search on continuous, map-like stimuli has been studied both in psychology and cartography. Earlier cartographic research using eye-movement methods has focussed mainly on paper map reading or the processing of static geographical information (Brodersen et al. 2001, Keates 1981, Lloyd 1997, Lloyd & Hodgson 2002, Nelson et al. 1997, Phillips & Noyes, 1977, Steinke 1987, Wolfe 1994, Wood 1993). Eye-movement studies conducted by cartographers have been either ”looking at map overall”- or task-based studies. Method has been used to improve cartographic design. Both the effect of age and experience has been studied. Subject groups have varied from children to adults, from experienced map users to novices. (Steinke 1987).

Eye movement recording is seen as a very promising method to study screen map reading. Since eye tracking reveals information of precise locations of eyes gazes or scanpaths, it may provide more specific information about problems in maps than traditional behavioral methods. Eye movement recordings also may provide useful information about strategies people use when they search for map objects. The problem is, however, that, even though eye movement analyses tell us what the user is fixating, it does not reliably give us information of where the user’s attention is directed nor what effect his/her percepts has on his/her way to interpret the world. There are also practical problems. For example, since the collection and analysis of eye movement data are time consuming, there is no sense to test a huge number of participants.

As Castner (1973;in Steinke 1987) suggests, it is useful to understand the reading strategies employed during task performance. We began analysing the procedures measuring the reaction times and fixation frequencies. Several processes are involved in transforming and interpreting sensory information extracted from a screen map. For example, capacity limitations of human memory systems have to be taken into account. According to Baddeley (1999), working memory is a subsystem of short-term memory. It has a controlling attentional system called the central executive, which supervises and coordinates a number of subsidiary slave systems. Two of those, the phonological loop and visuo-spatial sketchpad, are apparently necessary for maintaining information of the searched-for object. The role of long-term memory is also important. The long-term memory is a permanent store for experienced and learned data, from which the information can be retrieved to support the interpretation of the new incoming information.

3 Purpose of the Study

The purpose of this study was to acquire knowledge of people's perceptual and cognitive processes during a search for a map object. We also studied the effect of computer experience and the effect of people's knowledge about the map area. Knowledge of what is happening during search for map information is crucial for the development of more usable map interfaces. Modern map interfaces usually have some kind of a search function and the target appears automatically and clearly visibly on the screen. In order to better understand what users actually do when they use this kind of interface, we recorded users' eye movements.

Our main focus here was to study the role of manipulation of screen maps. We compared two methods of map advancement, scrolling and zooming, which are widely used in common screen map interfaces. By examining eye movements when searching for map objects we can learn more about the difficulties in map scanning. Our hypothesis was that experienced map users complete the tasks faster than novice users and their eye-movement patterns are more economical. We also hypothesized that the continuously-visible index map and the possibility to use the zoom option improve search performance.

4 Method

4.1 Participants

Eight participants volunteered, five of them females and three males. All of them had normal or corrected-to-normal vision. Four of them (two males and two females) were novice map users who have little experience in using screen map applications; four of them (one male and three females) were professional screen map and GIS users who have more experience on maps and especially on Helsinki metropolitan area map, the one used in the study. The novice users had earlier participated in eye-movement studies; for the experienced users it was the first time.

4.2 Apparatus

The stimuli were displayed on a Philips 170B 17" LCD/TFT flat panel monitor with a Dell Dimension 4100 computer. Display resolution was 1024 x 768 pixels. A chin rest was used to stabilize a participant's head.

4.3 Stimuli

Two program windows were shown side by side (see Figure 1). On the left hand side there was a MapInfo ProViewer (MI) window; on the right hand side there was a

PowerPoint (PP) window. Search was carried out on the MI window. Its size was 16° x 16° (in visual angle of degrees) from the viewing distance of 80 cm. An index map was shown on the PP window. Its size was 9° x 9°. At the beginning of a trial, the centre of Helsinki City was shown on the MI map with a yellow starting symbol. The scale of the map was about 1:20 000.

A larger portion of metropolitan area could be seen on the index map on the right side of the screen. Its scale was approximately 1:100 000 – 1:200 000. On the index map the participants could see both the yellow starting point and a red target point. The latter point they had to find according to the index map information. The target point was also shown on the MI map on the scale of 1:20 000 or when the screen map zoom level was more than 4 km, but it was not visible at the beginning of the trial.

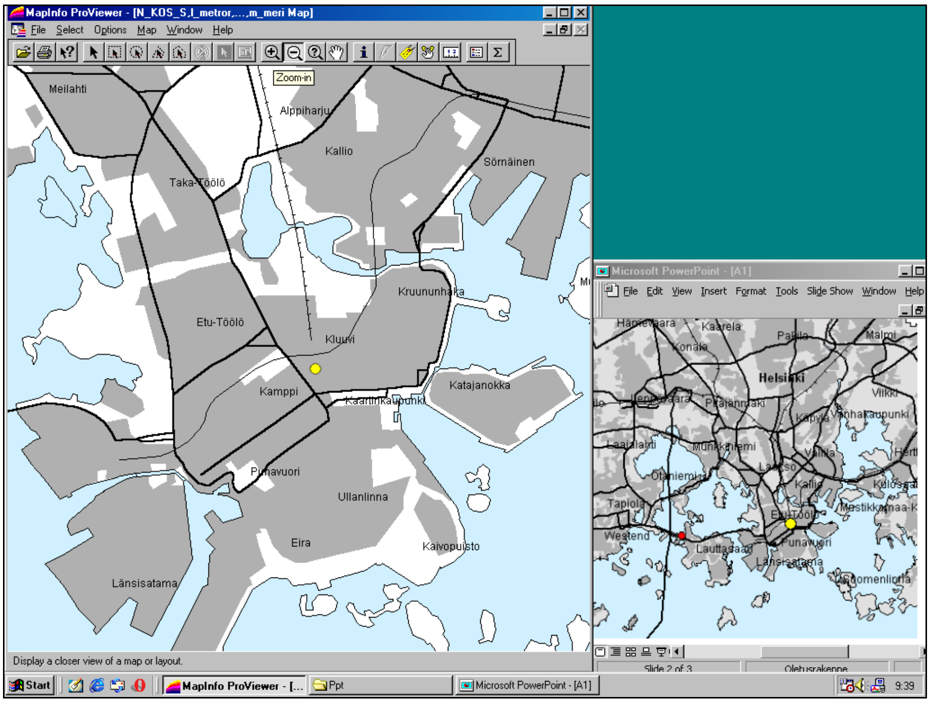

Fig. 1. An example of program windows at the beginning of a trial.

4.4 Background Map and Targets

The background map was neutral and but at the same time it was easily recognizable. It included information about the densely built-up area, railways, metro and roads. Shoreline, lakes and rivers were coloured in the same tint of blue and the airport areas were white. Place names were presented as district names. Municipal borders were coloured in black.

The target symbols were 12-point size circles, coloured in red, with black string around them (figure 2). The starting symbol was the same size but coloured in yellow. The red target symbols were located on three different zones on variable distance from the starting symbol: from 8 to 10 km, from 10 to 12 km and from 12 to 14 km. They were shown only one at a time. Targets were all located on the built-up area.

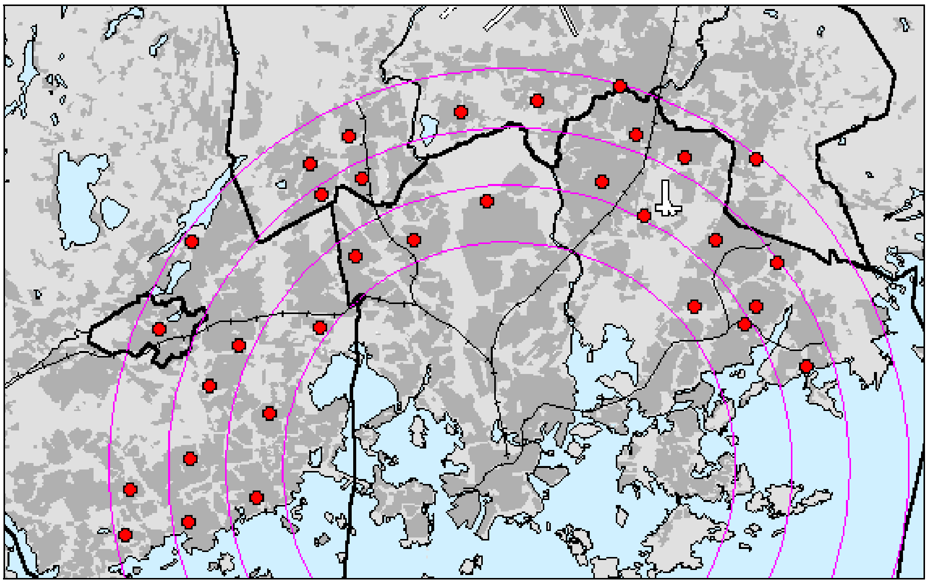

Fig. 2. All the 32 targets located on three zones. Only one target was presented on a map in a single trial.

4.5 Eye Movement Recordings and Definition of Fixation

Participants' eye movements were recorded using a head-mounted gaze tracking system (SMI iView). A participant's right eye was monitored with a miniature infrared camera while one infrared LED illuminated the eye. A PC computer controlled the eye tracking system.

Video images of the pupil and corneal reflections were captured at 50 Hz by the eye tracker. The eye movement system was calibrated using a set of 9 screen locations. iView-software was used to detect fixations and calculate their durations. To be considered a fixation, a gaze point had to fall within a spatial area between about 2 x 2 deg, and had a minimum duration of 80 ms.

4.6 Procedure

At the beginning of the experimental session participants had to complete a questionnaire concerning demographic information and other background data. After that they had to estimate their knowledge of the Helsinki metropolitan area by rating territories (on a printed test map) using a scale from 0 to 100. The results considering city knowledge are not reported in this paper. The session was divided in four experimental blocks. There were short pauses between the blocks. The eye-movement recording system was recalibrated between blocks. Each block consisted of 8 trials. The total number of trials was thus 32. The stimuli were presented in a counterbalanced order. Participants practiced each condition before performing the trials.

Participants' task was to find the target point on the MI map either by scrolling the map or by zooming in and out. The effect of scrolling and zooming was studied in alternating blocks. The experimenter told the participant whether he/she had to zoom or scroll in the next trial. In the scrolling condition the subject chose the scroll option from the menu bar, then clicked the mouse button down on the MI map, held it down and drag the map image in a desired direction and repeated the dragging process until the target was found. In the zooming condition the subject chose the zoom-in or zoom-out option from the menu bar, then clicked the mouse button down on the MI map as many times as he/she desired.

The index map - which is called as a cue - was either continuously visible on the PP window (index-map condition) or it was only flashed on the whole screen as a PowerPoint show dia for three seconds at the beginning of a trial (memory-map condition). At the end of the session, the experimenter interviewed each participant about the experiment and informed him/her of the purpose of the study. Participants were asked about target searching methods, reasons of difficulties on finding the target and other questions concerning the usability issues. The whole experiment took about 1.5 hours.

5 Results and Discussion

5.1 Reaction Times

Experienced map users found target objects faster than less experienced users. As can be seen in Figure 3, zooming was a slower method than scrolling for both groups. For novice users, reaction times were somewhat shorter if the index map was present throughout the trial. The results of three-way analysis of variance (ANOVA) confirmed these findings. The main effect of search method was significant ($p < 0.001$) as was the effect of user experience ($p < 0.01$). The effect of cue type was not, however ($p > 0.1$). Neither were any of the interactions significant ($p > 0.1$).

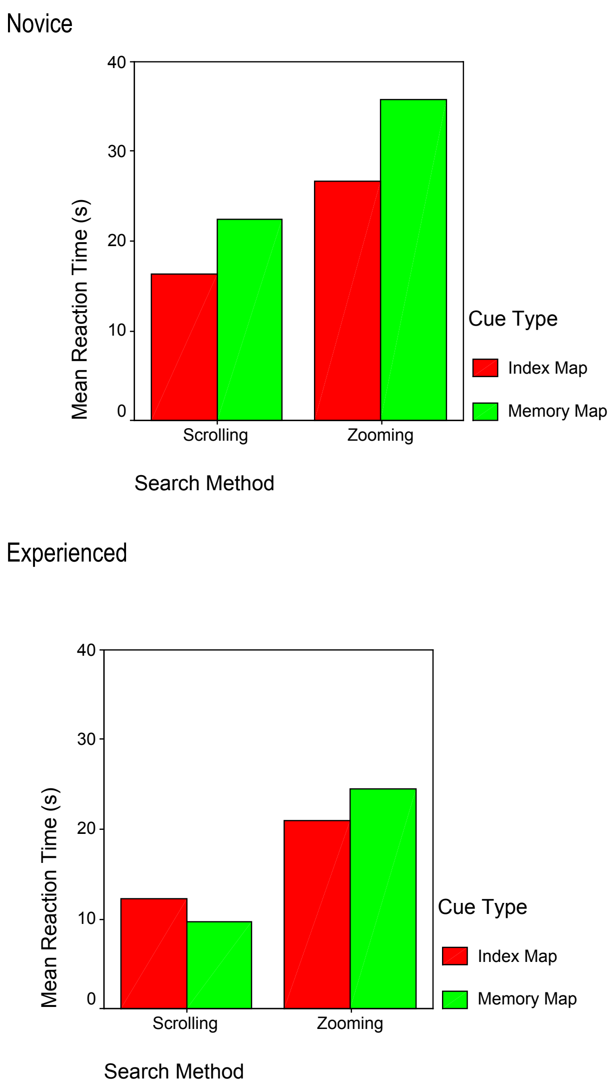

Fig. 3. Mean reaction times for novice and experienced users.

5.2 Eye Movement Data

A three-way repeated measures analysis of variance in which there were two within-subjects variables (search method, cue type) and one between-subject variable (user experience) was carried out on fixation duration data. Results revealed that the main effect of search method (scrolling vs. zooming) was significant ($p < 0.001$) as was the effect of user experience ($p < 0.05$). The effect of cue type was not significant, however, $p > 01$. Neither were any of the interactions significant ($p > 0.1$). The duration of fixations is smaller in the scrolling mode. Fixation durations were also shorter for experienced users.

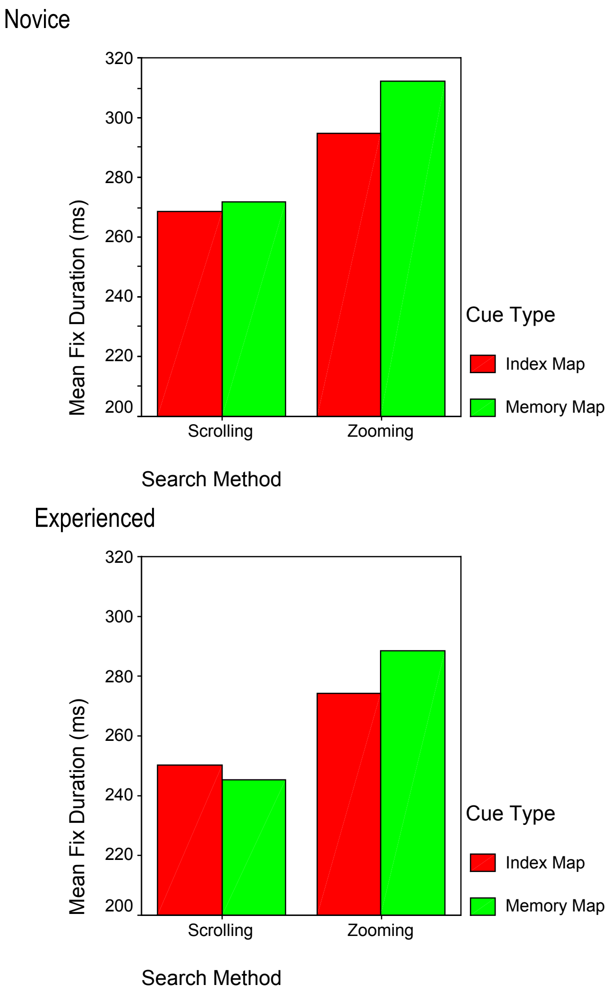

Fig. 4. Mean fixation durations for novice and experienced users.

Another three-way repeated measures analysis of variance (ANOVA) was carried out on fixation number data. The main effect of search method ($p < 0.01$) and the effect of user experience ($p<0.01$) were both significant, but the effect of cue type was not, $p> 0.1$. The number of fixations was smaller in the scrolling mode. Novice users also needed more fixations than experienced users.

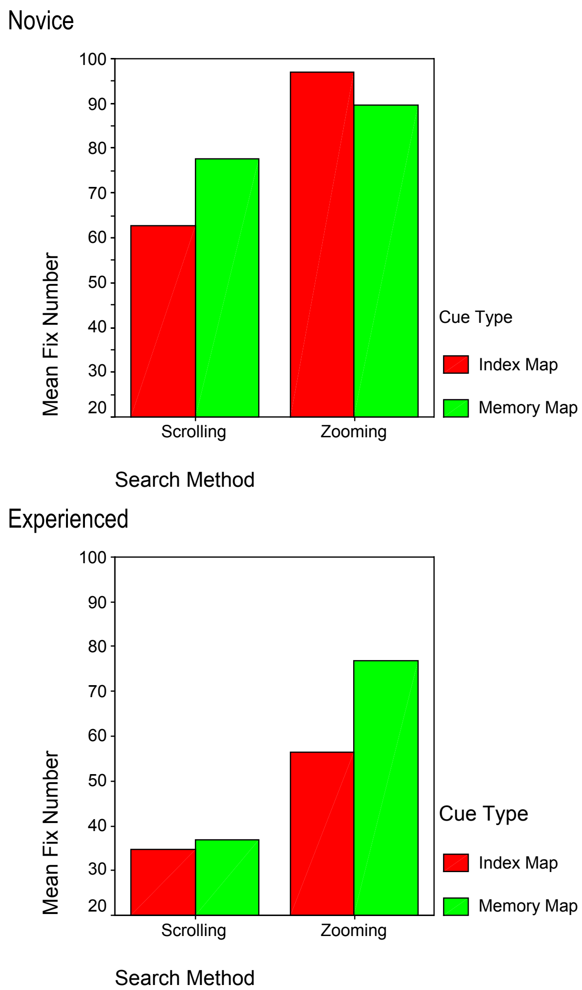

Fig. 5. Mean number of fixations for novice and experienced users.

Results suggest that scrolling is a somewhat more efficient method than zooming in searching simple map objects. User experience also had an effect on eye-movement measures. There are several reasons for this. The experienced map users had a larger experience with the application, they were more familiar with screen maps, and they used more efficiently the index map.

5.3 Regression Analysis

A regression analysis was carried out to explain the variation of reaction times with the help of 5-7 predicting variables. The main advantage of regression analysis is to take into account the entire set of variables simultaneously. Table 1 depicts 5 predictors and a constant term. The constant presents a (logarithmized) reaction time that is spent without estimated effect of other predictors. Index map 3 sec (memory map) indicates trials in which the participant had to remember the content of an index map. Zooming indicates trials in which only the zoom in or out -tool was permitted to use. Inner-variables indicate the zone of the target; stand for the target distance zones from the starting symbol. Inner3 was the furthest, 12-14 km far away from the city center. Novice is an inexperienced participant who has little experience on screen maps. The regression model can be stated in a generalized form:

$$Rtime = \beta_0 + \beta_1 Mem + \beta_2 Zoom + \beta_3 Inner2 + \beta_4 Inner3 + \beta_5 Novice \quad , (1)$$

where the β state for regressor coefficients. The variable symbols are presented in Table 1.

Table 1. The results of regression analysis.

Dependent Variable: Logarithmized reaction time (Rtime)

	Constant	Memory map (Mem)	Zooming (Zoom)	Inner2	Inner3	Novice
β	2.209***	-0.070	0.505***	0.119	0.338***	0.337**'
(Std. Error)	(0.094)	(0.070)	(0.070)	(0.091)	(0.091)	(0.070)
Sig.	0.000	0.320	0.000	0.192	0.000	0.000
R Square	Adjusted R Square					
0.265	0.251					

Standard errors are in parentheses. The asterisk labels (*) stand for the level of the statistical risk of denying incorrectly the null hypothesis: the regression coefficient is zero.

* 10 per cent risk level.

** 1 per cent risk level.

*** 0.1 per cent risk level.

R^2 describes how much the regression model explains out of the total variation of the dependent variable (log reaction time). Reaction times were logarithmized in order to reduce dispersion in the data and to form the relation linear between the dependent variable and predictors. Constant, Zooming, Inner3 and Novice lengthened significantly reaction times as was expected. Interestingly, reaction times also lengthened when zooming was used as a searching method. Showing the index map for 3 seconds as a memory map or during the whole trial did not affect significantly the reaction time. The predicted reaction time in the regression model 1 can also be presented as a following equation:

$$Rtime = 2.209 - .07Mem + .505Zoom + .119Inner2 + .338Inner3 + .337Novice \quad . \quad (2)$$

The second regression model contains two additional variables: number of fixations and duration of fixations that are logarithmized to linearize the relationship with the dependent variable. The model is now the following form:

$$Rtime = \beta_0 + \beta_1 NumFix + \beta_2 DurFix + \beta_3 Index + \beta_4 Zoom + \beta_5 Inner2 + \beta_6 Inner3 + \beta_7 Novice. \quad (3)$$

The names of variables are explained in Table 2.

Table 2. The results of regression analysis with the fixation data.

Dependent Variable: Logarithmized reaction time (Rtime)

	Constant	Ln number of fixations (NumFix)	Ln duration of fixations (DurFix)	Index map whole time (Index)	Zooming (Zoom)	Inner2	Inner3	Novice
B	3.159***	0.073	-0.235*	0.102	0.500***	0.123	0.328***	0.329***
(Std. Err.)	(0.827)	(0.056)	(0.135)	(0.071)	(0.070)	(0.091)	(0.091)	(0.076)
Sig.	0.000	0.195	0.084	0.155	0.000	0.177	0.000	0.000
R Square	Adjusted R Square							
0.282	0.262							

Standard errors are in parentheses. The asterisk labels (*) stand for the level of the statistical risk of denying incorrectly the null hypothesis: the regression coefficient is zero.
* 10 per cent risk level.
** 1 per cent risk level.
*** 0.1 per cent risk level.

The second regression analysis was carried out to explain the variation of reaction times with the help of fixation data (Table 2). We found that number of fixations did not explain significantly the reaction time. Surprisingly, fixation durations seemed to reduce the reaction time in the data. The finding tells about careful examination of the screen map and the participants's concentration on the search process. The use of zooming, searching target from the inner3 zone and a novice status had a significant effect on the reaction time. The estimators in Table 2 can be plugged into Equation 3, which results:

$$Rtime = 3.159 + .073 NumFix - .235 DurFix + .102 Index + .5 Zoom + .123 Inner2 + .328 Inner3 + .329 Novice. \quad (4)$$

The equations 2 and 4 presents the specific predictive models for reaction time estimated from the data at hand. Despite some differences in the magnitude of the estimators, the two models result the similar qualitative conclusions. Being novice user and zooming the target in an inner3 zone enhance the reaction time. Furthermore, the second model offers new insight for the impact of duration of fixations, which seemed to reduce reaction time.

The findings suggest that the fixation data might be structured in different manners in some subgroups of the data. For instance, it would be important to separate the subgroup specific or even person-related features that affect the reaction time but cannot be perceived in the ANOVA or regression analysis above.

5.4 Interviews

After completing the 32 trials we interviewed every participant. They gave their opinions of the search method, the usage of an index map and their preferences concerning map search. Preferences varied notably between participants. Some participants also gave contradictory answers. Five participants preferred scrolling over zooming, three participants preferred zooming. Two of them were experienced map users and one novice. Overall, participants thought that the index map was presented long enough in the memory-map condition. Only one novice user claimed that the presentation time was too short. Most of the participants also thought that it is better if the index map is available throughout the trial. Some participants thought that the index map was somewhat distracting.

We also asked subjects about their strategies according to find the target. Overall, the strategies tended to be quite similar. All participants told that they used graphic elements like roads, railroads, lakes and shoreline. Some participants responded that they tried to remember names and districts of the town. Others seemed to memorize the index map as a schematised drawing.

6 Conclusions and Further Research

At the outset of this paper, it was suggested that experienced map users would require shorter reaction time and fewer fixations to perform the task. A clear effect of user experience was found: the experienced map users found the target object faster than novice users. Eye-movement data also suggest that the experts' search performance was more efficient: the number and the duration of their fixations were lower than novices'. Further research questions will be posed in order to find other variables affecting positively to reaction times.

It was assumed that zooming would be more efficient search method than scrolling. However, scrolling was found to be a faster method for map advancement than zooming. Only in the index- map condition the experienced users needed more time for scrolling than in the memory-map condition. Zooming required more fixations and the duration of the fixations were also longer than with scrolling. Since the participants could not use both methods during a single trial, we do not know whether the combination of these two methods is even more efficient.

It was also assumed that reaction times would be shorter if the index map is available throughout a trial. The mode of presentation of the index map had only a small effect. The participants could quite well remember the location of the searched-for object even when the index map was flashed only shortly beforehand. Some participants claimed the index map even disturbing. They tended to look at it continuously instead of trusting on their own memory. There is thus no need to present the index map throughout the trial, but it is good if it is available all the time.

The experienced map users both interpret and analyse map information more efficiently. Therefore, index maps are more useful to them. Perhaps index maps have to be tailored for different kind of users. For example, novice users may need simpler index maps. More efficient methods for map advancement are needed. There is a great need for methods, which make it possible to smoothly combine zooming and scrolling. Perhaps totally new kinds of metaphors/analogies are needed for moving around a map.

The statistical variables behaved differently in different parts of the data. Therefore, a method that provides more detailed information, such as factor analysis, might be useful. For example, factors analysis might find some specific features explaining the reaction time within some specific subset of the participants. Special measures of eye-movement data, such as scanpath duration and length, number of and duration of gazes on different areas of interest and number of scrolling and zooming operations per trial will also be examined.

References

Appleyard, D. (1970). Notes on Urban Perception and Knowledge. In Downs & Stea (1970) *Image and Environment*, 109 - 144. Aldine/Chicago.

Baddeley, A. (1999). *Human Memory*. Psychology Press, UK.

Brodersen, L., H.H.K. Andersen & S. Weber (2001). Applying Eye-Movement Tracking or the Study of Map Perception and Map Design. *Publications Series* 4:9, Kort & Matrikelstyrelsen, National Survey and Cadastre, Denmark.

Burnett, C. & R. Kalliola (2000). Maps in the Information Society. *Fennia* 178:1, 81-96. Helsinki.

Cartwright, W., J. Crampton, G. Gartner, S. Miller, K. Mitchell, E. Siekierska & J. Wood (2001). Geospatial Information Visualization, User Interface Issues. *Cartography and Geographic Information Science*, 28:1, 45-60.

Castner, H (1973). Electrooculography in Cartographic Research. A Paper Presented at Canadian Association of Geographers Annual Meeting, Mimeograph.

Gilhooly, K.J., M. Wood, P.R. Kinnear & C. Green (1988). Skill in Map Reading and Memory of Maps. In *The Quarterly Journal of Experimental Psychology* 40A (1), 87-107.

Keates, J.S. (1982). *Understanding Maps*. Longman, London

Lloyd, R. (1997). Visual Search Processes Used in Map Reading. *Cartographica* 34:1, 11-31.

Lloyd, R. & M. Hodgson (2002). Visual Search of Land Use Objects in Aerial Photographs. *Cartography and Geographic Information Science* 29:1, 3-15.

Logie, R.H. (1995). *Visuo-Spatial Working Memory*. Lawrence Erlbaum Associates, Publishers.

McEachren, A. (1995). *How Maps Work*. Guilford, New York.

Nelson, E. S., D. Dow, C. Lukinbeal & R. Farley (1997). Visual Search Process and the Multivariate Point Symbol. *Cartographica* 34:4, 19-33.

Phillips, R. J. & Noyes, L. (1977). Searching for Names in Two City Street Maps. *Applied Ergonomics* 8, 73 – 77.

Slocum, T.A., C. Block, B. Jiang, A. Koussoulakou, D.R. Montello, S. Fuhrmann & N.R. Hedley (2001). Cognitive and Usability Issues in Geovisualization. *Cartography and Geographic Information Science*, 28:1, 61-75.

Steinke, T.R. (1987). Eye Movement Studies in Cartography and Related Fields. Studies in Cartography, Monograph 37, *Cartographica* 24:2, 40-73.

Wolfe, J.M. (1994). Visual Search in Continuous, Naturalistic Stimuli. *Vision* 34:9, 1187-1195.

Wood, C.H (1993). Visual search centrality and minimum map size. *Cartographica* 30:4, 32-44.